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(54) BUOYANCY CONTROL APPARATUS FOR SUBMERSIBLE VESSELS

(71) I, OSCAR FERRER MUNGUET, of Balmes 188, 6°, 1ª, Barcelona - 6, Spain, of Spanish nationality, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to buoyancy control apparatus for submersible vessels.

Several types of buoyancy control apparatus are known for use in raising sunken vessels, diving dresses, and diving bells as well as for vessels such as submarines. However, all such apparatus are manual or involve little automatic control which results in slow operation as well as not being very efficient and safe, since they depend unduly upon the human factor. Also, these apparatus can cause considerable losses of gas due to forced expulsion of this in each change of level in successive series of rises and falls in depths.

An object of the present invention is to overcome these disadvantages, in order that the apparatus referred to can be compared in its functioning to the operation of the natatorial bladder system of a fish. This system, in accordance with the explanations of Giuseppe Colosi, Director of the Zoological Institute of the University of Florence, in its work "Marvels of the Sea", makes the tissues and other organs of the fish suitable to resist the pressure at any submarine depth in spite of its natural fragility. The natatorial bladder of the fish, in this case, is equivalent to a space full of gas, maintained at an internal pressure perceptibly equal at all times to the pressure of the exterior where it is placed and which, as it is known, can vary in pressure at any moment, according to depth and other factors.

According to the invention there is provided buoyancy control apparatus for submersible vessels comprising a compressor, a variable volume container mounted on the vessel so as to be submerged when the vessel is submerged and connected to the input and the output of the compressor, storage vessels connected between the compressor output and the container, means for controlling flow from the compressor output to either the container or the vessels and means for controlling flow from the vessels to the container.

In order that the invention and its operation may be readily understood, several embodiments are described below in conjunction with the accompanying drawings, in which:

Fig. 1 shows a preferred embodiment of the buoyancy control apparatus of the invention;

Fig. 2 shows another embodiment of part of the apparatus, i.e. the main container, shown in Fig. 1;

Fig. 3 shows another embodiment of the main container;

Fig. 4 shows diagrammatically a two-cylinder compressor of an alternative type to that forming part of the apparatus shown in Fig. 1;

Fig. 5 shows diagrammatically a three-stage compressor, which can be used instead of the compressor used in the general assembly of the apparatus according to the invention;

Fig. 6 shows diagrammatically a known form of multi-cylinder compressor which may replace the compressor used in the apparatus of Fig. 1;

Fig. 7 shows a longitudinal vertical section through a vessel in which apparatus according to the invention has been installed;

Fig. 8 shows a modification of the apparatus of Fig. 7;

Fig. 9 shows a regulating pendulum for controlling horizontal stability of a vessel fitted with the apparatus of the invention during immersion;

Fig. 10 shows a half-transverse cross-section of a submarine hull, illustrating another possible installation of the apparatus according to the invention.

The apparatus may be used either to

control the depth of a submarine equipped with a pressure hull, by varying the ratio of gas to water in its ballast tanks or to maintain the air pressure inside a surface vessel which has been adapted for underwater travel but does not have a pressure hull capable of withstanding the external water pressure. In either case, as shown in Fig. 1, the basic components of the apparatus may be located outside the habitable hull 2 of the submarine or the vessel, except for the necessary controls. A two-stage compressor 1 is mounted outside the hull 2, together with its associated electric motor, to which it is drivingly connected in known manner. The compressor 1 comprises a first-stage cylinder 7 and a second-stage cylinder 8. Admission and exhaust valves of the first-stage cylinder 7 are indicated at 3 and 4 respectively, and the corresponding admission and exhaust valves of the second-stage cylinder 8 are indicated at 5 and 6. A safety valve 9 for avoiding excessive over-pressure in the cylinder 7 is provided while an automatic control device 10, 11 for controlling the final pressure established in the first-stage cylinder 7 during operation is also provided. The control device 10, 11 operates to automatically throttle the gas entering the compressor and is described and claimed in co-pending Application No. 32749/71 (Serial No. 1,262,137) which has been divided out of the present application.

A three-way valve 13, which is operated electrically by a switch 28 described in detail below, can be operated so that gasses pass from first-stage cylinder 7 via the outlet valve 4 and then the inlet valve 5 to the second-stage cylinder 8 or instead to a delivery line 14 which, like the line 12, is connected to a container 15, which in this case is a ballast tank of a conventional submarine. A third line 16 is connected via the exhaust valve 6 of the second-stage cylinder 8 to a series of high pressure bottles 17.

The ballast tank or container 15 communicates at the bottom with the water outside the vessel, so that this water rises in the container to a level, indicated at 21, corresponding to the position of equilibrium at the particular depth of the submerged submarine. Inside the container 15 above the level of the water, there is a space 19 which is occupied by gas, so that, for a constant amount of gas, the water will rise from the level 21 to a higher level 22 or will fall to a lower level 20, in accordance with any increase or decrease of the depth and therefore of the pressure of the water outside. These variations of level inside the container 15 cause corresponding movement of a float 23. This is connected by a rod 44 to one end of a two-armed lever 24, the other end of which is an actuator for a valve 27 and, if required, also for the electric switch 28. Displacement of the float 23 causes the lever 24 to actuate the valve 27 or the electrical switch 28, according to the direction of the movement of the arms of the lever 24. A control member 26, operated from the interior of the hull 2, actuates a small electric motor 25 which is coupled to the lever 24 and also to the rod 44 attached to the float 23. Operation of the motor 25 not only permits the float to rise or fall independently of the level the water has reached inside the container 15, but also reverses the operation of the lever 24, as will be described below. This occurs while the operator maintains the control member 26 in operation, i.e. so as to obtain the desired level inside the container 15, as marked or signalled by corresponding indicators.

The valve 27 is located in the line 16 and is connected by another line 43 to the upper part of the container 15, so that actuation of the valve 27 by rising of the float 23 connects the space 19 in the container 15 with the bottles 17.

As regards operation of the buoyancy control apparatus according to the invention, there are three cases to consider, first, when the submarine is motionless at a predetermined depth; second, when there are desired changes in its depth along a given vertical line: and third, when the submarine is navigating under-water. In these three cases of immersion, the compressor 1 (Fig. 1) should have been started from the first moment of immersion.

In the first case, the float 23 occupies a constant level inside the tank 15, as for instance the level 21, so that the space 19 occupied by gas also contains a constant mass of air or gas which is subject to a pressure equal to that of the exterior water at that depth. Under these circumstances, the compressor 1 withdraws a constant volume of gas from the space 19, by means of the tube 12, in order to return it, in each cycle of compression, to the same space 19 by means of the tube 14, while the second-stage cylinder remains inactive, and the valve 6 closed, because of the constant pressure of the gas contained in the bottles 17. In this position of equilibrium for the submarine at such constant depth, if a descent to the seabed were to begin, as the pressure of the exterior water increases and the gas in the space 19 is compressed, the level of the water within the tank 15 rises together with the float 23, and this makes the lever 24 operate to open the valve 27, so that then air or gas is sent into the space 19 from the bottles 17 through the tube 43, until the float 23 recovers its initial level 21, when the lever 24, having gained its neutral position, causes the valve 27 to close again. If, on the contrary, the submarine has ascended to the surface,

the air or gas contained in 19 would have been expanded, because of the lower pressure of the external water, causing the float 23 to descend, for instance to the level 20, making the lever 24 operate the electrical switch 28, in order to actuate the three-way valve 13 and so cause the gas exhausted from the first-stage cylinder 7 to be transferred to the second-stage cylinder 8, instead of returning to the space 19, in order to be compressed and stored in the bottles 17 after going through the exhaust valve 6 and the line 16, until the float 23 finally regains its neutral or original level 21, when the lever 24 no longer operates the switch 28.

In the second case, i.e., if it is desired to change depth along the vertical, this is obtained by changing from the level 21 where the float 23 is initially, either to a lower position 20, if one wishes to ascend to the surface, or to a higher level 22, if it is desired to descend to a greater depth. Thus, when it is desired to reduce depth or to ascend, it is only necessary for the operator in the habitable hull to operate the switch or control 26 so as to cause operation of the small electric motor 25, in order to shorten the telescopic rod 44 which connects the float 23 to the lever 24, in such a way that the float 23 is made to descend to the desired level 20. At the same time, the lever 24 now operates in the opposite direction to the previous case, i.e., it now actuates the valve 27, so as to cause the air or gas coming from the bottles 17 to be sent to the space 19, until the water inside the tank 15 reaches the desired lower level 20 and as indicated by visual signals or indicators in the interior of the habitable hull. When this occurs, the operator manipulates the control 26, so as to leave the components as they were previously, with the exception of the new setting for the float 23 and the corresponding shorter length of the telescopic rod 44, for the actual neutral position of the lever 24. On the contrary, if one desires to descend to a greater depth, the operator manipulates the control 26 in the opposite direction, so as to cause reverse operation of the small electric motor 25, in order that the telescopic rod 44 becomes extended and so causes the float to occupy a higher position, for instance the level 22; at the same time, the lever 24 acts in the opposite direction to the previous case, i.e., acting on the switch 28 in order to cause the second stage cylinder of the compressor to come into action and so cause air or gas to be extracted from the space 19 and to be stored in the bottles 17, for the time during which the level of the water within the tank 15 has not reached the higher level 22, as indicated or signalled in the interior of the habitable hull, at which moment the operator ceases to operate the control 26, thus leaving the components as they were before, with the exception of the new setting for the float 23 and a longer length of the telescopic rod 44, for the actual neutral position of the lever 24.

In the third case, i.e., when the submarine is already navigating underwater using its propellers and depth vanes, the principal advantage of the apparatus according to the invention lies in that it acts as a safety device to give a warning if the submarine descends to an excessive depth which could result in deformation or even crushing of the habitable hull. Thus if the safe limiting depth for the submarine under normal conditions is exceeded, at which depth it is not possible for the control device 10, 11 to prevent the final pressure inside the cylinder from reaching a maximum value, this maximum pressure operates the safety valve 9, which in turn, through for example a suitable electrical connection starts any kind of alarm. Further, if preferred, the apparatus can be arranged to initiate either the introduction of air into the ballast tanks or an adjustment of the depth vanes until the submarine has returned to a lesser depth, without the need of any surveillance on the part of the crew. No less interesting in this aspect of safety during underwater navigation is the possibility of actuating an alarm indicating excessive depth always a little before the limit of safety for the submarine has been reached, by simply graduating the maximum throttling capacity by means of the control device 10, 11, so that this limit is reached a few metres before the admissible maximum depth. Under these conditions of underwater navigation, it would not be necessary for all the elements related with the lever 24 and the float 23 to operate, as it is sufficient for the compressor 1 to operate continuously, by drawing in air or gas from the space 19 and returning it to the space, since the submarine normally maneouvres when submerged by means of its rudders, vanes and propellers and so variation of the level of the water inside the tank 15 is not particularly significant.

Another improvement in safety during underwater navigation includes the addition of a hammer operated by a cam moved by the revolutions of the compressor. This hammer can be arranged to contact a bell or a membrane at one or more points inside or outside the hull of the submarine, in such a way that the sound given by the resultant hammering is a signal for the crew that something is not working properly, so that a return to surface is indicated. In Fig. 10, the compressor 1 is installed close to the habitable hull 81, in the case where the hammer is used to hit the hull and where the other parts of the apparatus are installed inside one of the ballast tanks of the external structure 82.

As regards other advantages of the apparatus shown in Fig. 1, in addition to the

three fundamental cases already described, the compressor 1 can be used during surface navigation to fill the normal bottles of air in such vessels, apart from the bottles 17, by drawing air in directly from the atmosphere through the valve 18, for instance, assuming the latter is independent of the tank 15.

The container or tank 15 was described in relation to the Fig. 1 as having an opening at the bottom, so as to establish communication with the external water and it is evident that this construction can be varied in many different ways within the scope of the present invention.

Thus, in Fig. 2, for instance, another construction for the tank 15 is illustrated, this time being of a compact and elastic type, in such a way that the space 19 for the gas constitutes the interior of the container. In this case, it is evident that the construction and expansion of the elastic walls 45, subjected in use to the pressure of the external water, would cause corresponding actuation of the rod 44 and its attached elements 24, 25 and 26, in a similar way to that described for the analogous components represented in Fig. 1. In the same way, the auxiliary rod 46 indicates contraction or expansion of the elastic walls, equivalent to the levels 20, 21 and 22 mentioned in connection with the previous embodiment.

Another example of construction of the tank or container 15 is shown in Fig. 3, for those cases in which it is not convenient for the exterior water to pass directly into the tank 15.

An auxiliary container 49 and the main container 15 are interconnected and contain a fluid 48 which is of a different density and is not miscible with water. The water enters the auxiliary container 49 through a pipe 47, so varying the level in the auxiliary container and thus the level in the main container to actuate the float 23.

Regarding other possible constructions for the compressor 1, it is evident it can be of any other type, including rotary compressors. Piston compressors, when used, can be of a very simple construction, such as those having an even multiple of cylinders as shown in Figs. 4 and 6, particularly when the need is to navigate at a small depth or when dealing with low pressures in the storing of air or gas in the bottles 17, since in such cases these compressors may be even of the single stage type. Naturally, in cases in which it is more convenient to use air or gas under high pressure, it would be preferable to use two or more stages, like the one illustrated in Fig. 5. In the latter case, while the cylinder 52 operates as described in connection with Fig. 1, the remaining cylinders 53 and 54 serve to fill the bottles 17. It is possible, naturally, to interchange the first and second stage cylinders and also combine them in other ways.

Referring now to the use of the invention in connection with light structures, as for instance surface vessels or aircraft these can easily be made for submerged use or underwater navigation without basic reinforcement of their structures. The following description is of a real case of a surface vessel, built in the usual way with water-tight compartments formed by means of transverse bulkheads, as used in certain merchant ships, particularly oil tankers, like the one shown in Fig. 7 with the reference 54. In this vessel, the water-tight compartments are indicated at 55, 56, 57, 58, 59, 60, 61, 62 and 63. Reference 62 corresponds to the engine compartment, which in the present example has for propulsion a diesel engine of the multi-cylinder type, as is usual in such ships and as shown in Fig. 6.

As is known, this type of engine is started by compressed air previously stored in bottles, so that in this example it can be assumed that the filling of such bottles is done by using one or two cylinders of the same engine as compressors, while the other cylinders serve to give power in the normal way. In Fig. 7, 64 indicates the superstructure, usually found in the stern of this type of vessel, while 21 represents the level of the water when navigating on the surface.

For the case of immersion being described, this oil tanker has been provided with a habitable chamber 65 in which can be located not only the principal controls for the immersion, but also in which those members of the crew in charge of the engine, etc. can remain when not occupied in the engine compartment 62. At 66 is indicated a structure in the form of a hollow main mast, intended to contain or protect tubes for the admission of air and the exhaust of combustion products to and from the propulsion engine. The structure is also for use during navigation when submerged near the surface, and in this connection it may house an auxiliary periscope and serve to support a small external observation post, in the top end 67, near the surface or level 22, as shown in Fig. 7. This column or hollow mast 66 can also be used by the crew to leave the vessel when, in an emergency, it would be advisable or convenient not to return it to the surface. In order to ensure stability during navigation in the submerged condition, the vessel 54 would be provided with depth vanes 68, of known type.

With the vessel 54 so fitted out, the apparatus of Fig. 1 is installed so that the compartment 59 acts as the tank 15 shown in Fig. 1, i.e., after being provided with the corresponding auxiliary elements so that it can function as described in connection with the tank 15. The bow and stern

compartments or tanks 55 and 63 are partially filled with oil, so that this floats on the water obtained from the exterior and filling the remainder of such tanks; this ensures the horizontal stability of the vessel, for instance by transferring oil by means of a circulating pump from one tank to the other and under the control of an automatic device explained later. The remaining compartments 56, 57, 58, 60 and 61 are filled completely with oil or in the known way with water, so as to prevent damage to the metal walls because of the pressure of the external water. Regarding the compartment 62 used as the engine room, this may be maintained full of air at a pressure substantially the same as that of the external water, in the usual way; in the first case, this can be easily achieved by connecting the top of the compartment 62 with the top of the central compartment 59.

When the vessel is to be submerged, this can be done by flooding the tanks or ballast spaces with external water, until the corresponding level is reached, so as to cause submergence to a level similar to 22, in which only the top end 67 is slightly above the surface and the same engine used during surface propulsion can also be utilized for navigation. Thus, because of the apparatus controlling the air or gas within the tank or compartment 59, already described in connection with Fig. 1, the crew will then not have any trouble in maintaining the pressure of the gases in compartment 59 and other spaces connected therewith, such as the compartment 62, i.e., since this pressure is of a similar value to that of the water in which the vessel is navigating. At the time for returning to the surface, it will be sufficient to drain the tanks or ballast spaces of the water previously admitted at the time of immersion, in order to return the corresponding conditions of flotation.

Fig. 8 illustrates another vessel in which the invention may be used, which vessel can be allowed to descend to a greater depth than that usually permitted by the limited length of the hollow mast 66. In Fig. 8, it can be seen that flexible tubes 69 are connected to a cable 70 which is attached to a floating buoy 71 towed from the same vessel 54 or fitted with its own means of propulsion. These flexible auxiliary tubes 69 allow for the corresponding air admission to and exhaust products from the internal combustion engine of the submerged vessel, which in this manner can now continue operating at such a greater depth.

Regarding the automatic levelling device permitting proper operation for the circulating pump intended to interchange liquids between the tanks or compartments 55 and 63, this device consists essentially of a pendulum 72, as illustrated in Fig. 9 which when the vessel inclines one way or the other acts either on a contact 73 or an opposite contact 74 and so permits the operation of the circulating pump in the correct direction, until the horizontal stability of the vessel is regained.

As regards the practical use of such alternatives according to Figs. 7 and 8, referring to petrol-tankers, for instance, the invention provides a means of enabling a tanker to navigate underwater, e.g. in wartime or in bad weather conditions. Underwater navigation reduces the risk of fire and another important advantage is that no special harbour for effecting loading and discharge is required, even in the case of very large petrol tankers, since when the latter reach the vicinity of a very small harbour, they may be submerged to reach the bottom at low depth, from which convenient lengths of tubing interconnecting the vessel with the harbour could be used for loading or discharge, even in bad weather. Since a pertol tanker consists of various water-tight compartments interconnected by means of tubes, the application of the present invention would not involve any significant cost.

It is evident that adaptation of such vessels as shown in Figs. 7 and 8 for underwater operation would not be very costly, when utilising the same internal combustion engines when submerged as when on the surface.

These adaptations using internal combustion engines already mounted in a petrol-tanker, for both uses as shown in Figs. 7 and 8, can be carried out readily, especially by anyone who had already carried out a complete design of an aquatic-motor according to my Patent No. 685,601 so as to obtain when submerged a similar power as when on the surface and with the same diesel engine, utilizing at least one of its cylinders only for compression. The remaining engine cylinders continue to be utilized as combustion cylinders, as mentioned in the previous paragraph.

In the case of a multi-cylinder compressor such as that shown in Fig. 6, it is possible to use cylinders 77, 78, 79 and 80 as compressors, each cylinder being a compressor for separate buoyancy apparatus operating on the separate ballast compartments. This results in greater safety.

As regards the use as the compressor 1 of any of the cylinders of the propulsion engine of the vessel, while the remaining cylinders continue acting as power cylinders in the usual way, changes can be made which in certain cases can offer special advantages. Thus, when requiring to maintain or increase the driving power for surface navigation, in spite of working the engine with a lesser number of cylinders, some supercharging under special known circumstances can be used.

As regards the regulating capacity of the apparatus at a certain depth, the apparatus can cause regulation at each revolution of the compressor 1, and therefore, with great speed. It is also evident that stabilization of a vessel can be improved by employing a gyroscope to control the buoyancy of the tanks relative to each other.

In the case of a diver who has to reach a depth of about 300 metres using as an atmosphere a mixture of oxygen and helium, then the corresponding graduated dose at any successive depth could be obtained by installing the apparatus of Fig. 1 to control or regulate the helium in circulation as well as control the buoyancy. In this case, the bottles 17 are filled with helium, and the gas in the space 19 feeds the breathing mask of the diver after it has been enriched with oxygen from a further bottle provided with a suitable dosing-valve controlled by the external water pressure, the products resulting from the diver's breathing being returned to the space 19, after being purified or cleaned as necessary.

It is evident that the present invention is also applicable to vehicles and apparatus other than vessels normally navigable in or on water.

In summary, it can be seen from the previous description that the present invention enables naval structures or vehicles of any kind to be operated in different surroundings or atmospheres submerged by means of only slight modifications, while the same invention it is also possible to adapt trucks, wheeled capsules or tanks to run over the bottom of the sea, by simply adding to their structures the necessary elements or accessories, e.g. as in accordance with Fig. 7.

WHAT I CLAIM IS:—

1. Buoyancy control apparatus for submersible vessels comprising a compressor, a variable volume container mounted on the vessel so as to be submerged when the vessel is submerged and connected to the input and the output of the compressor, storage vessels connected between the compressor output and the container, means for controlling flow from the compressor output to either the container or the vessels and means for controlling flow from the vessels to the container.

2. Apparatus as claimed in claim 1, having means for controlling the compressor output within predetermined limits.

3. Apparatus as claimed in claim 1 or 2, including means for producing a warning signal when the pressure in the container exceeds a predetermined value.

4. Apparatus as claimed in any preceding claim, having control means operated by the varying volume of the container for actuating the means for controlling flow from the compressor output and the means for controlling flow from the storage vessels.

5. Apparatus as calimed in any preceding claim in which the container is open to the medium in which the vessel is submerged.

6. Apparatus as claimed in claim 5 when dependent on claim 4, in which the control means is connected to a float device responsive to the level of medium in the container.

7. Apparatus as claimed in any one of claims 1 to 4 in which the container has elastic walls.

8. Apparatus as claimed in claim 7 when dependent on claim 4, in which the control means is connected to a movable portion of the container.

9. Apparatus as claimed in claim 4, 5 or 6, having an auxiliary container in direct communication with the medium in which the vessel is submerged and with the main container, whereby the pressure of the medium in the auxiliary container is transmitted to the main container by means of an intermediate fluid.

10. Apparatus as claimed in any preceding claim, in which the compressor is a two-stage compressor, the output from the second stage being connected to the storage vessels and the input to the second stage being connected to the means for controlling flow to either the container or the storage vessels.

11. Apparatus as claimed in any preceding claim, in which at least one cylinder of a multi-cylinder internal combustion engine is used as the compressor.

12. Apparatus as claimed in claim 1, in which the container is a submarine ballast tank, a portion of the interior of a surface vessel, a land vehicle, an aircraft or a spacecraft.

13. Buoyancy control apparatus substantially as hereinbefore described with reference to the accompanying drawings.

14. A vessel, diving dress or other equipment capable of submerging when provided with apparatus according to any preceding claim for use as an excess depth device.

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FIG.1.

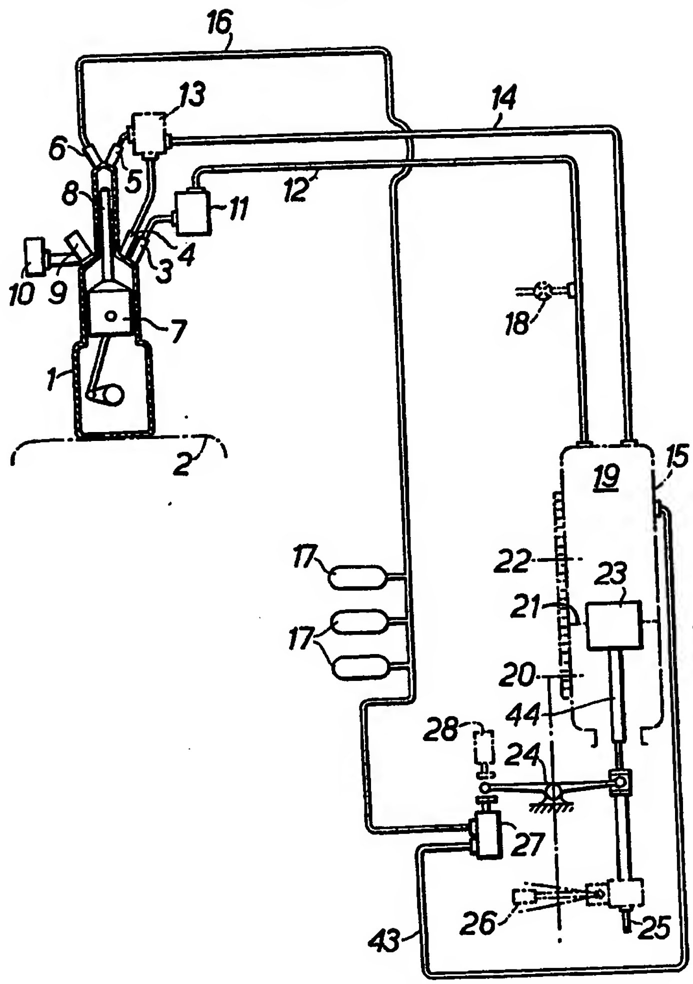
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FIG.2.

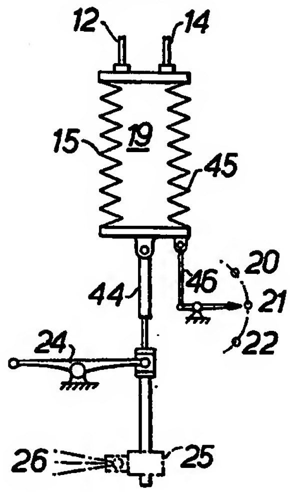


FIG.3.

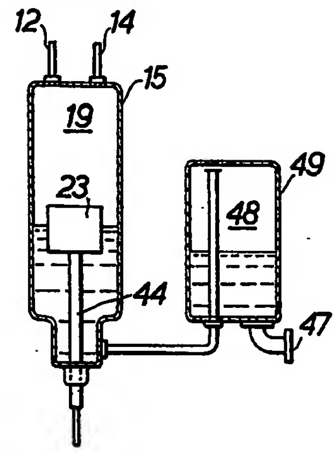


FIG.4.

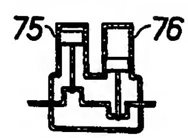


FIG.5.

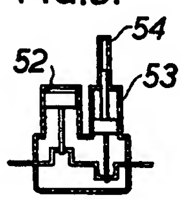


FIG.6.

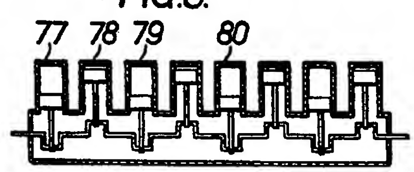


FIG. 7.

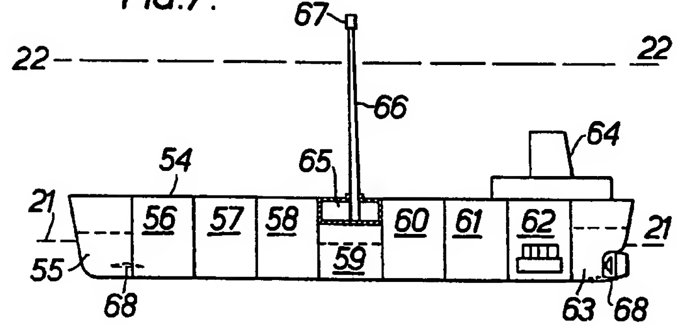


FIG. 9.

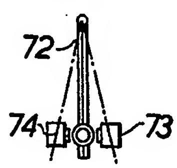
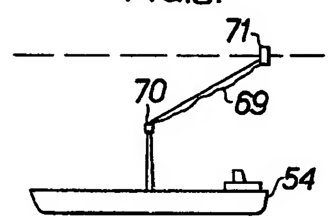


FIG. 8.



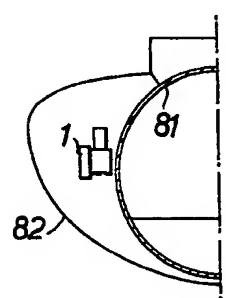


FIG. 10.